Comparing MOBILE6.2 and Emfac2007 Emission Factors for Mobile Source Air Toxics

Submission Date: November 15, 2007

Word Count: 6873

Michael Claggett, Ph.D. (corresponding author)
Air Quality Modeling Specialist
Federal Highway Administration Resource Center
4001 Office Court Drive, Suite 800
Santa Fe, New Mexico 87507
(505) 820-2047
Michael.Claggett@dot.gov

Jeffrey Houk
Air Quality Specialist
Federal Highway Administration Resource Center
12300 West Dakota Avenue, Suite 340
Lakewood, Colorado 80228
(720) 963-3203
Jeff.Houk@dot.gov

Abstract. Top on the list of tools needed to reliably forecast any potential adverse health outcomes from proposed highway projects is, predictably, mobile source emission factor models. This paper provides a comparison of the two current regulatory models – Emfac2007, developed by the California Air Resources Board for applications in California and MOBILE6.2, developed by the U.S. Environmental Protection Agency for regulatory applications elsewhere in the nation. Mobile source air toxic (MSAT) emission factors computed by the models are evaluated. While the two models share the same fundamental principal, i.e., emissions from motor vehicles are based on testing with correction factors utilized to account for on-road vehicle use; the models produce strikingly divergent results for some MSAT compounds. And Emfac2007 predicts higher MSAT emissions for a supposedly cleaner vehicle fleet. The reasons for these calculation differences are discussed. The implications pertaining to the evaluation of highway project alternatives are also discussed.

INTRODUCTION

Our reliance on mobile source emissions modeling is growing in an attempt to understand and mitigate potential adverse air quality effects of ever-increasing vehicle travel on the nation's highways. The origin of such modeling is to predict episodic emission events of carbon monoxide and ozone precursors due to motor vehicle activity. The design of the two regulatory mobile source emission factor models used today was predicated on fulfilling this purpose. It is essential that a consensus understanding of on-road motor vehicle emissions be developed, especially in the emerging field of mobile source air toxics (MSAT).

In the present regulatory structure, potential changes in mobile source emissions among transportation alternatives are evaluated using the U.S. Environmental Protection Agency's (EPA) MOBILE6.2 model (*1*) for most of the nation or the California Air Resources Board's (CARB) Emfac2007 model (*2*) in that state, along with forecasts of vehicle miles of travel (VMT). Emission factor predictions obtained from the models are based on empirical measurements, generally conducted in laboratory settings, with numerous adjustments made to account for locale-specific circumstances, including external conditions, vehicle fleet characteristics, vehicle activity, vehicle fuel specifications, and state programs. The models' utility in forecasting magnitudes and trends of MSAT emissions for the long-term is somewhat limited because of their regulatory makeup. Future predictions are made within the context of environmental regulations that have been enacted. They do not account for changes in technologies and laws that are likely to occur over the timeline of a public health assessment relating to motor vehicles, fuels, and/or emission controls.

Nevertheless, some insights may be gained concerning the evaluation of MSAT emissions among highway project alternatives by comparing predictions using the nation's two regulatory mobile source emission factor models for a current and future condition.

MOBILE6.2 EMISSION FACTORS

The U.S. EPA's MOBILE6.2 model (dated 24-Sep-2003) was run to forecast annual emission factors of selected mobile source air toxic (MSAT) compounds (acetaldehyde, acrolein, benzene, 1,3 butadiene, formaldehyde, and diesel particulate matter). FHWA's Easy Mobile Inventory Tool (EMIT) (*3*) was utilized as an interface to MOBILE6.2 to facilitate the creation of look-up tables of annual average emission factors versus vehicle speed.

Emission factors for two calendar years were evaluated: 2005, representing a current or baseline condition and 2030, representing a design year condition. When computing annual average emission factors, the U.S. EPA (*4*) recommends that monthly emission factors be developed via mathematical interpolation between January and July and the monthly results summed. The U.S. EPA's (*4*) simplified interpolation scheme was adopted applying month by month variations in temperatures and humidity. Median values from the distribution of daily average minimum and maximum temperatures measured across the U.S. were used in the analysis as were daily average absolute humidity derived from relative humidity values (refer to Table 1).

Emission factors of diesel particulate matter (PM) include the organic carbon, elemental carbon, and sulfate portions of diesel exhausts for the maximum particle size cutoff of 10 μm that can be considered in the MOBILE6.2 model. The diesel fuel sulfur level used is consistent with the 49-state average value reflecting more stringent federal controls (i.e., 11 ppm for 2030). For

TABLE 1 External Condition Parameters Used in the MOBILE6.2 Modeling

Month		Evaluation Month	Temperature (°F)		Humidity		Calendar Year
			Min	Max	Abs (gr/lb)	Rel (%)	
January	1	1	23.5	41.0	73	19.3	Year
February	2	1	26.2	45.6	71	21.7	Year
March	3	1	33.6	54.4	68	28.6	Year
April	4	7	41.2	63.2	66	37.8	Year
May	5	7	50.5	72.5	67	53.9	Year
June	6	7	59.3	81.7	70	77.4	Year
July	7	7	64.0	86.1	71	92.0	Year
August	8	7	62.4	84.8	73	90.0	Year
September	9	7	55.1	77.3	72	68.5	Year
October	10	1	43.8	66.0	70	44.3	Year + 1
November	11	1	35.1	53.1	72	30.4	Year + 1
December	12	1	26.8	43.9	73	21.9	Year + 1

the baseline year of 2005, an average diesel fuel sulfur level of 350 ppm was assumed. The analysis was based on the 2007/2020 30 ppm sulfur gasoline specifications for the northeastern states with no reformulated fuel program (*5*). The design year case accounts for the U.S. EPA's MSAT rule (*6*) promulgated earlier this year, which limits the benzene content in gasoline to 0.62% by 2011. However, the MOBILE6.2 model does not reflect the new hydrocarbon exhaust standards imposed by the rule. Emission reductions that may be realized from a local inspection/maintenance program or anti-tampering program were not considered in the analysis. The fuel assumptions employed in the MOBILE6.2 modeling are summarized in Table 2.

The analysis was conducted accounting for the hydrocarbon (HC) emission components specific to vehicle operation on freeways and arterials, e.g., running exhaust and running evaporative losses. The evaluation relied on the VMT fractions by vehicle type calculated internally by the MOBILE6.2 model based on the specified calendar year of evaluation and from national average default data for: 1) vehicle population for the 16 composite vehicle classes; 2) vehicle registration by age distribution; 3) diesel fractions; and 4) mileage accumulation rates. A single distribution is computed to represent the fraction of total highway VMT accumulated by each of 16 combined vehicle types for a day. Speed look-up tables of emission factors were constructed by employing the AVERAGE SPEED command and specifying vehicle speeds from 5 mph to 65 mph in 1 mph increments for freeway and arterial roadway scenarios.

EMFAC2007 EMISSION FACTORS

The CARB's Emfac2007 model (version 2.30 dated 01-Nov-2006) was run to forecast annual emission factors of MSAT compounds in much the same way as the MOBILE6.2 model. The differences inherent in the MOBILE6.2 and Emfac2007 modeling are highlighted in the next section. Statewide average emission factors of HC as total organic gases (TOG) and total particulate matter were computed for 2005 and 2030 using default data values provided by the Emfac2007 model. The default annual average temperature and relative humidity values are 61 °F and 66%, respectively. Consistent with the MOBILE6.2 modeling, emission reductions that may be realized from a local inspection/maintenance program or anti-tampering program were

TABLE 2 Fuel Parameters Used in the MOBILE6.2 Modeling

Parameter	Season	
	Winter	Summer
Reid Vapor Pressure (psi)	13.2	8.6
Aromatic Content (%)	23.1	27.1
Olefin Content (%)	14.1	9.9
Benzene Content (%)	0.73	1.03
E200 (%) [a]	51.8	44.4
E300 (%) [b]	83.3	81.1
MTBE Content (%)	0.6	3.4
Diesel Sulfur (ppm)	11.0	11.0

[a] Vapor percent of gasoline at 200 °F
[b] Vapor percent of gasoline at 300 °F

not taken into account in the analysis. Similarly, the Emfac2007 TOG emission factors were based on the running exhaust and running evaporative loss components. Translating TOG emission factors to the HC-based MSAT compounds was accomplished using CARB speciation ratios developed by the UC Davis-Caltrans Air Quality Project (*7*). These are a general conservative representation of the detailed information published by CARB. Diesel PM emission factors were calculated from the three components of diesel exhaust for the maximum particle size cutoff of 30 μm that can be considered in the Emfac2007 model. Speed look-up tables of emission factors were constructed by specifying vehicle speeds from 5 mph to 65 mph in 1 mph increments for direct comparison with MOBILE6.2 emission factors.

CONTRASTING METHODOLOGIES AND DATA

The MOBILE6.2 and Emfac2007 models share the same basic concept – emission factors are based on empirical measurements conducted for vehicles operated during prescribed drive cycles to simulate typical trips. MOBILE6.2 is based on numerous facility driving cycles (*8*) to simulate vehicle travel on freeway and arterial roadway types for different levels of service (i.e., congestion categories), plus local streets and freeway ramps at fixed speeds; while Emfac2007 is based on a single, area-wide unified cycle (*9*). Since the measurements are conducted primarily under laboratory conditions using established protocols, adjustment factors are employed to reflect in-use and local-specific conditions such as vehicle tampering, aggressive driving, air conditioning, temperature, speed, fuel, etc.

There are, however, inevitable differences in the emission factor results produced by Emac2007 and MOBILE6.2 solely because of the contrast in information used to represent the circumstances in California versus the rest of the nation. These include differences in:

- vehicle emissions and fuel standards;
- external conditions, such temperature and humidity and methodologies for interpolating to annual emission conditions;
- vehicle fleet characteristics, such as registration distributions, mileage accumulation rates, and diesel fractions;
- vehicle classifications and VMT mix among the vehicle types; and

- vehicle fuel specifications.

MOBILE6.2 calculates and reports emission factors for the HC-based MSAT compounds by applying appropriate weight ratios of TOG. The weight ratios vary by fuel type, technology group, vehicle type, whether a vehicle is a normal or high emitter, and gasoline specifications. With Emfac2007, TOG emission factors produced by the model and weight ratios based on information furnished by CARB as implemented in the UC Davis-Caltrans Air Quality Project are used to determine emission factors of the HC-based MSAT compounds. Tables 3 and 4 provide the contrasting weight ratios employed in this analysis for calendar year 2005 and 2030, respectively.

RESULTS

Resulting TOG emission factors generated by the MOBILE6.2 and Emfac2007 models are presented in Figure 1 for calendar year 2005 and 2030 for a full range of vehicle speeds. The most obvious discrepancy in the model predictions is for the minimum vehicle speed of 3 mph. The scale of the ordinate axis on the left panel of Figure 1 masks to some extent the divergence in TOG emission factors calculated by the models for the other vehicle speeds in calendar year 2005. Perhaps less ambiguous contrasts are provided in Figure 2, which shows the percent differences in TOG emissions from MOBILE6.2 compared to Emfac2007. An additional calendar year is added for comparison – 2010, to represent the first year of operation of a highway project.

The next series of charts provide the same information presented for TOG emission factors, but specific to the selected MSAT compounds considered in the analysis. The emission factors computed with MOBILE6.2 and Emfac2007 as well as the percent differences in emissions, respectively, in Figures 3 and 4 for acetaldehyde; Figures 5 and 6 for acrolein; Figures 7 and 8 for benzene; Figures 9 and 10 for 1,3 butadiene; Figures 11 and 12 for formaldehyde; and Figures 13 and 14 for diesel PM.

CONCLUSIONS

Although the same basic concept was used in developing the MOBILE6.2 and Emfac2007 mobile source emission factor models, widely disparate results are produced for selected mobile source air toxic compounds. In both models, emission factors for the HC-based MSAT compounds are determined by applying weight ratios of TOG. The MOBILE6.2 and Emfac2007 models forecast remarkably similar TOG emission factors for the near-term calendar years 2005 and 2010 through out most of the vehicle speed range. This result is somewhat unexpected because of the supposedly cleaner vehicle fleet in California versus the rest of the nation. The notable exception is for extremely slow vehicle speeds. This has important implications with respect to suggested applications for air quality modeling of signalized intersections. A critical parameter in such applications is the idle emission factor, typically determined from the minimum vehicle speed. MOBILE6.2 predicts significantly higher TOG emission factors compared to Emfac2007 for calendar year 2030 throughout the vehicle speed range. This result is also somewhat unexpected, because the vehicle emission control standards implemented in California are expected to be fully implemented in the rest of the nation by 2030.

MOBILE6.2 generally predicts higher emission factors for acrolein, benzene, and 1,3 butadiene compared to Emfac2007. Emfac2007 generally predicts higher emission factors for

TABLE 3 Toxic Weight Fractions of TOG Emissions for the 2005 Analysis Year

Fuel Type / Technology Group / Vehicle Type	Acetaldehyde			Acrolein			Benzene			1,3 Butadiene			Formaldehyde		
	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007
	Winter	Summer		Winter	Summer		Winter	Summer		Winter	Summer		Winter	Summer	
Gas Catalyst															
LDGV (normal emitter)	0.0050	0.0062		0.0006	0.0006		0.030	0.040		0.0042	0.0031		0.020	0.042	
LDGV (high emitter)	0.0049	0.0061	0.0055	0.0006	0.0006	0.0015	0.026	0.034	0.028	0.0042	0.0035	0.0066	0.019	0.036	0.021
LDGT	0.0050	0.0062		0.0006	0.0006		0.023	0.030		0.0042	0.0032		0.019	0.038	
HDGV	0.0050	0.0062		0.0005	0.0005		0.038	0.044		0.0027	0.0017		0.019	0.038	
Gas Non-Catalyst															
LDGV (normal emitter)	0.0063	0.0078		0.0006	0.0006		0.0300	0.0398		0.0095	0.0110		0.025	0.037	
LDGV (high emitter)	0.0063	0.0076	0.0055	0.0006	0.0006	0.0015	0.0257	0.0340	0.028	0.0094	0.0104	0.0066	0.024	0.033	0.021
LDGT	0.0063	0.0077		0.0006	0.0006		0.0228	0.0302		0.0095	0.0110		0.025	0.035	
HDGV	0.0067	0.0067		0.0045	0.0045		0.0228	0.0302		0.0070	0.0054		0.036	0.040	
MC	0.0063	0.0077		0.0006	0.0006		0.0228	0.0302		0.0095	0.0110		0.025	0.035	
Diesel															
LDDV	0.012	0.012		0.0035	0.0035		0.020	0.020		0.0090	0.0090		0.039	0.039	
LDDT	0.012	0.012	0.074	0.0035	0.0035	0.0000	0.020	0.020	0.020	0.0090	0.0090	0.0019	0.039	0.039	0.15
HDDV	0.029	0.029		0.0035	0.0035		0.011	0.011		0.0061	0.0061		0.078	0.078	
Running Evaporative	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0028	0.0076	0.010	0.000000	0.000000	0.000069	0.0000	0.0000	0.0000

TABLE 4 Toxic Weight Fractions of TOG Emissions for the 2030 Analysis Year

Fuel Type / Technology Group / Vehicle Type	Acetaldehyde			Acrolein			Benzene			1,3 Butadiene			Formaldehyde		
	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007	MOBILE6.2		Emfac2007
	Winter	Summer		Winter	Summer		Winter	Summer		Winter	Summer		Winter	Summer	
Gas Catalyst															
LDGV (normal emitter)	0.0050	0.0062		0.0006	0.0006		0.029	0.035		0.0042	0.0031		0.020	0.042	
LDGV (high emitter)	0.0049	0.0061	0.0025	0.0006	0.0006	0.0011	0.025	0.030	0.021	0.0042	0.0035	0.0047	0.019	0.036	0.014
LDGT	0.0050	0.0062		0.0006	0.0006		0.022	0.027		0.0042	0.0032		0.019	0.038	
HDGV	0.0050	0.0062		0.0005	0.0005		0.038	0.042		0.0027	0.0017		0.019	0.038	
Gas Non-Catalyst															
LDGV (normal emitter)	0.0063	0.0078		0.0006	0.0006		0.0287	0.0352		0.0095	0.0110		0.025	0.037	
LDGV (high emitter)	0.0063	0.0076	0.0025	0.0006	0.0006	0.0011	0.0246	0.0301	0.021	0.0094	0.0104	0.0047	0.024	0.033	0.014
LDGT	0.0063	0.0077		0.0006	0.0006		0.0219	0.0267		0.0095	0.0110		0.025	0.035	
HDGV	0.0067	0.0067		0.0045	0.0045		0.0219	0.0267		0.0070	0.0054		0.036	0.040	
MC	0.0063	0.0077		0.0006	0.0006		0.0219	0.0267		0.0095	0.0110		0.025	0.035	
Diesel															
LDDV	0.012	0.012		0.0035	0.0035		0.020	0.020		0.0090	0.0090		0.039	0.039	
LDDT	0.012	0.012	0.074	0.0035	0.0035	0.0000	0.020	0.020	0.020	0.0090	0.0090	0.0019	0.039	0.039	0.15
HDDV	0.029	0.029		0.0035	0.0035		0.011	0.011		0.0061	0.0061		0.078	0.078	
Running Evaporative	0.0000	0.0000	0.0000	0.0000	0.0000	0.0000	0.0024	0.0045	0.010	0.000000	0.000000	0.000069	0.0000	0.0000	0.0000

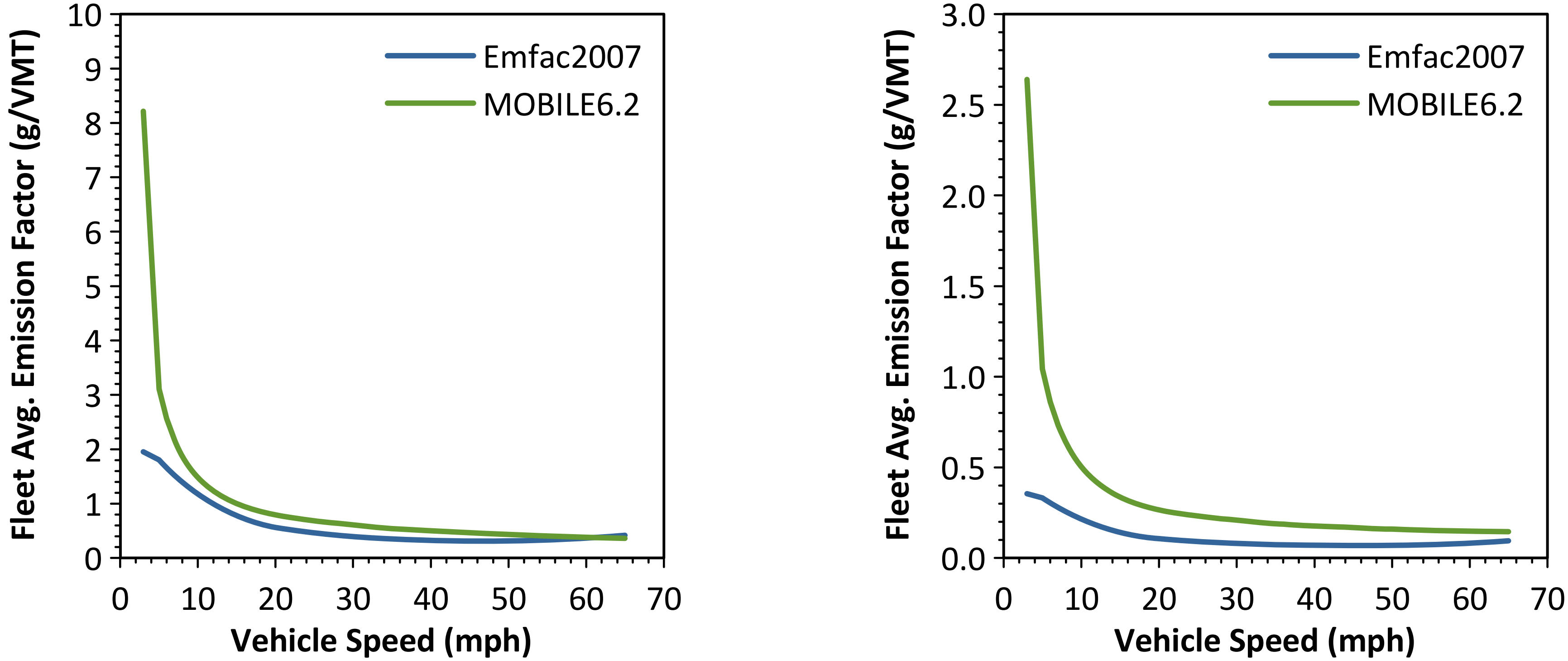

FIGURE 1 Emission factors of total organic gases for calendar years 2005 (left panel) and 2030 (right panel).

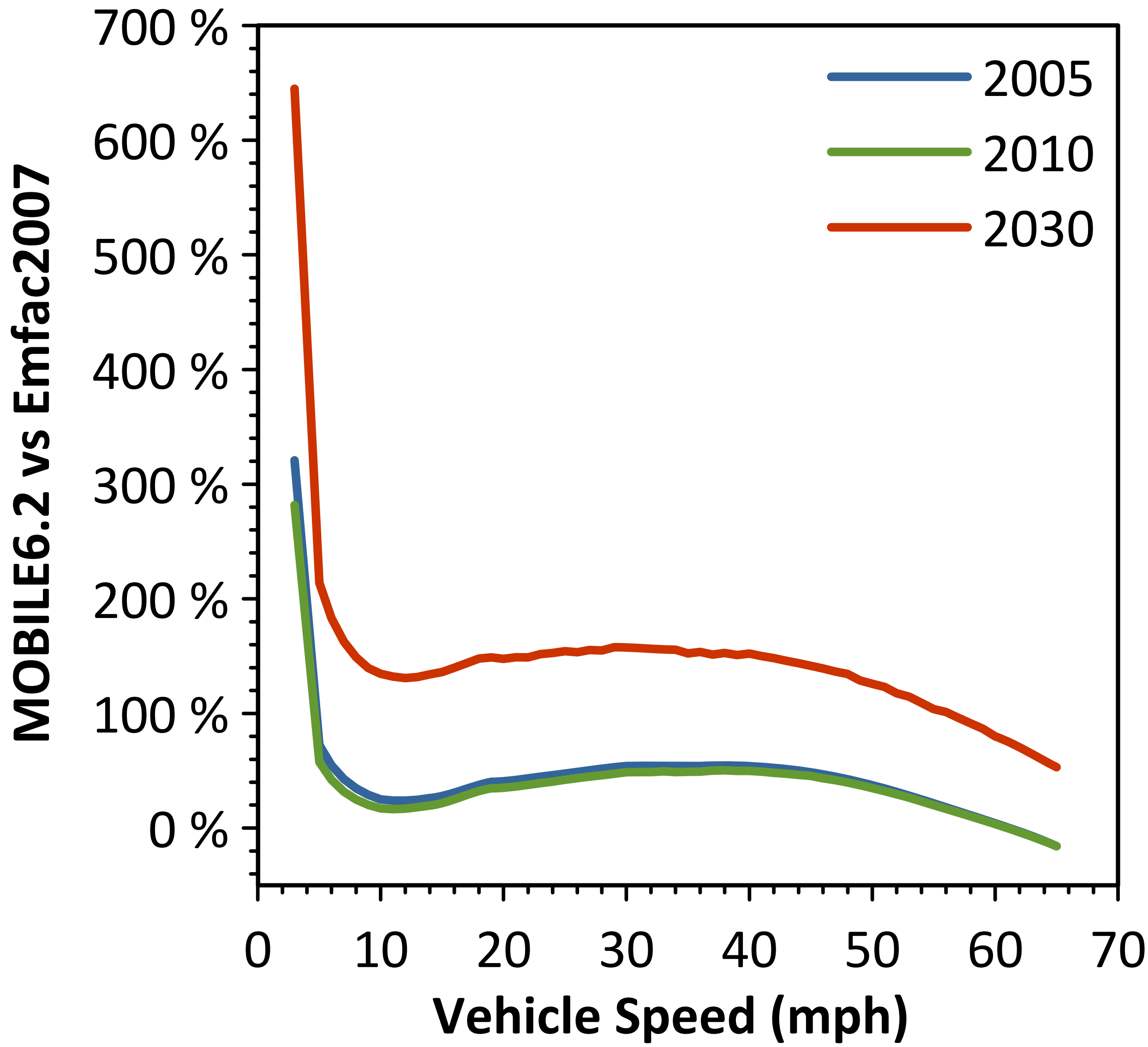

FIGURE 2 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of total organic gases.

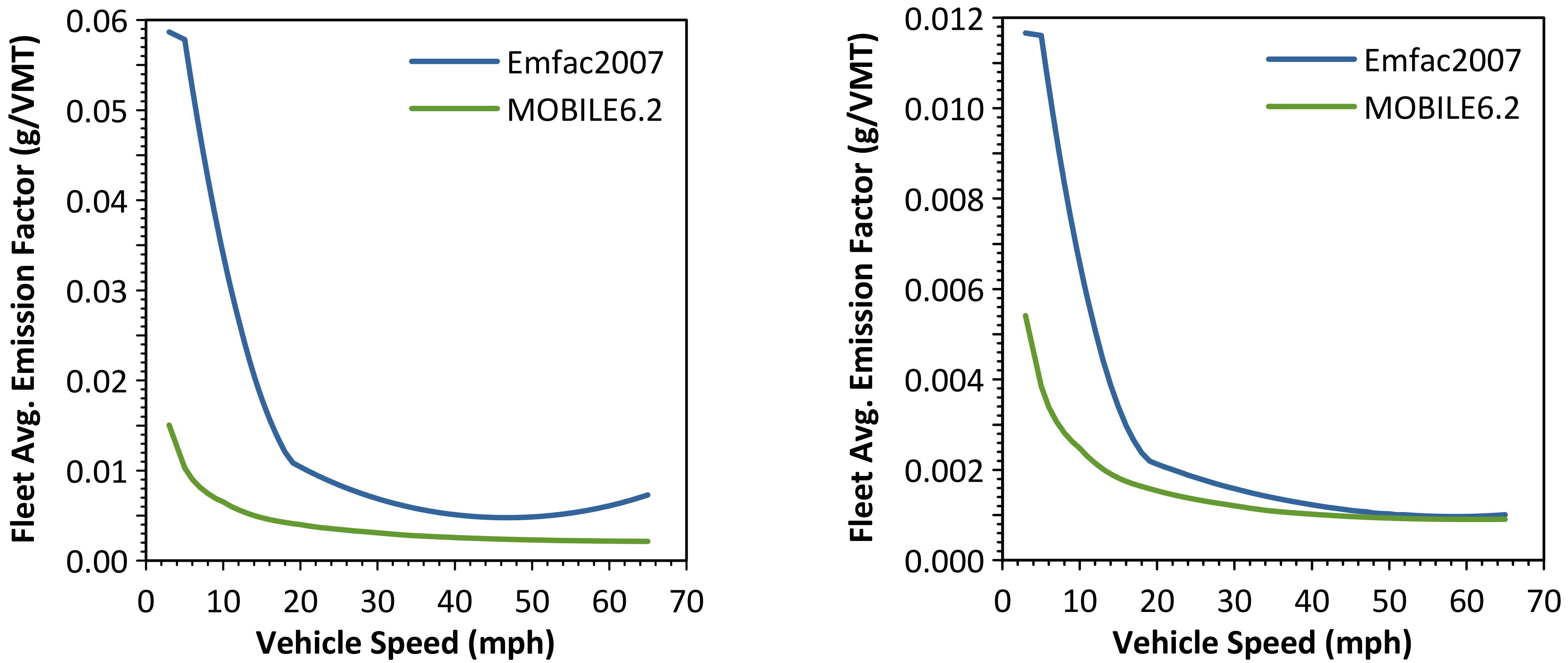

FIGURE 3 Acetaldehyde emission factors for calendar years 2005 (left panel) and 2030 (right panel).

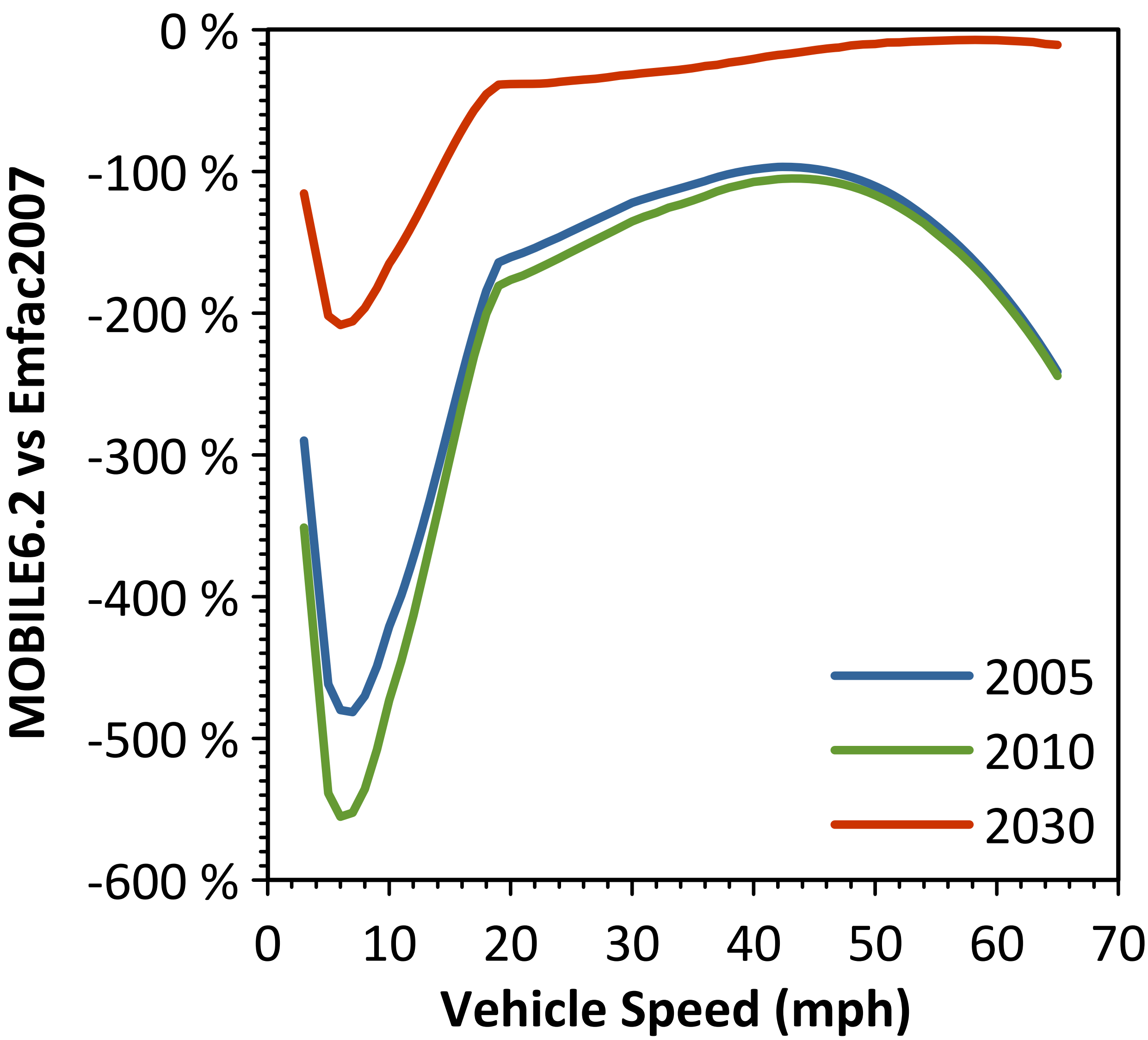

FIGURE 4 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of acetaldehyde.

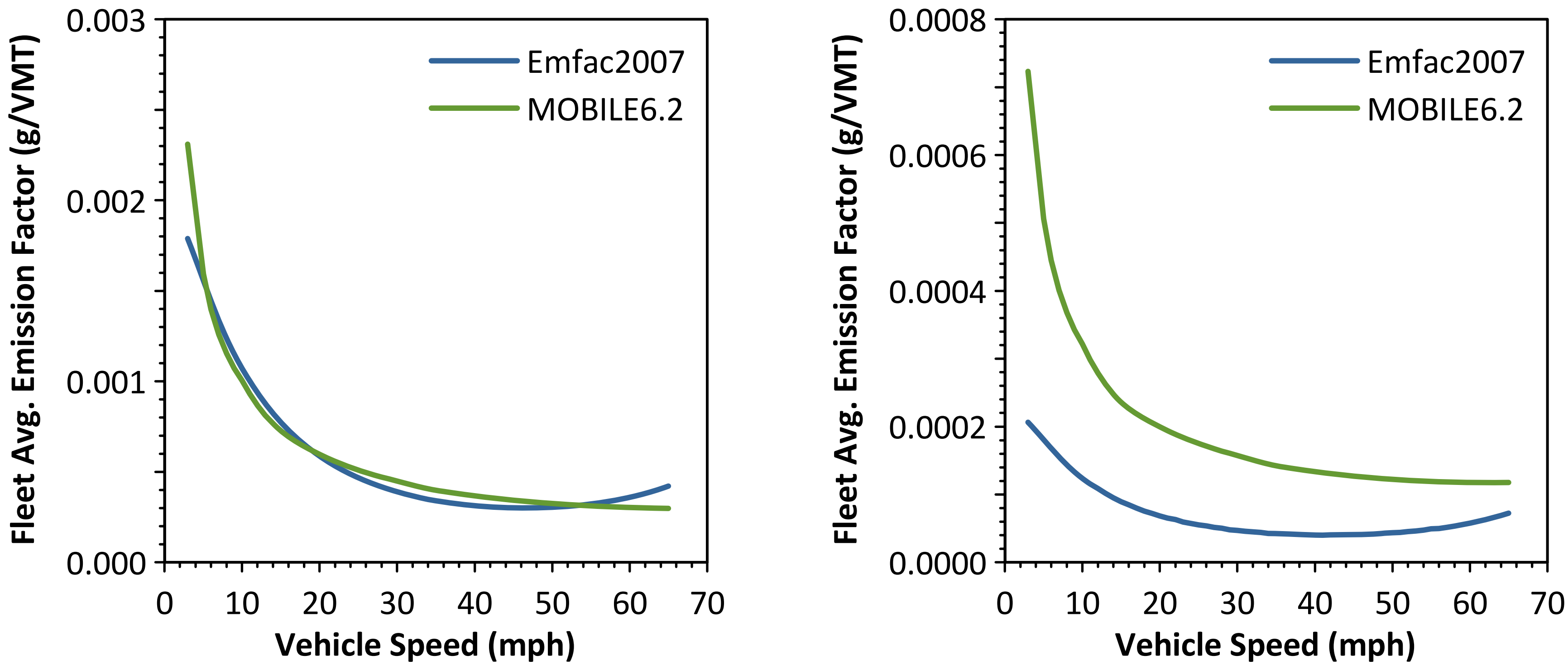

FIGURE 5 Acrolein emission factors for calendar years 2005 (left panel) and 2030 (right panel).

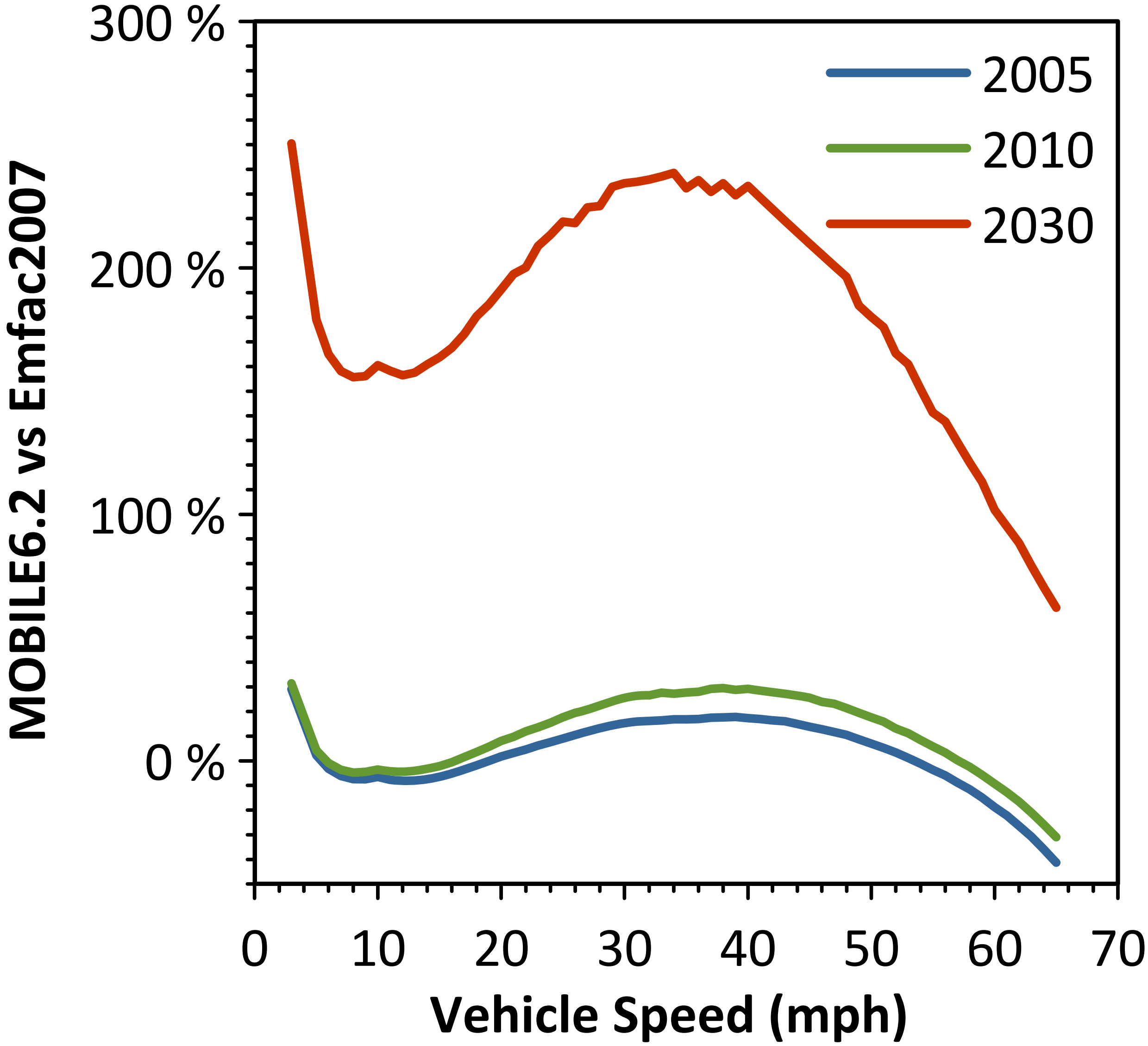

FIGURE 6 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of acrolein.

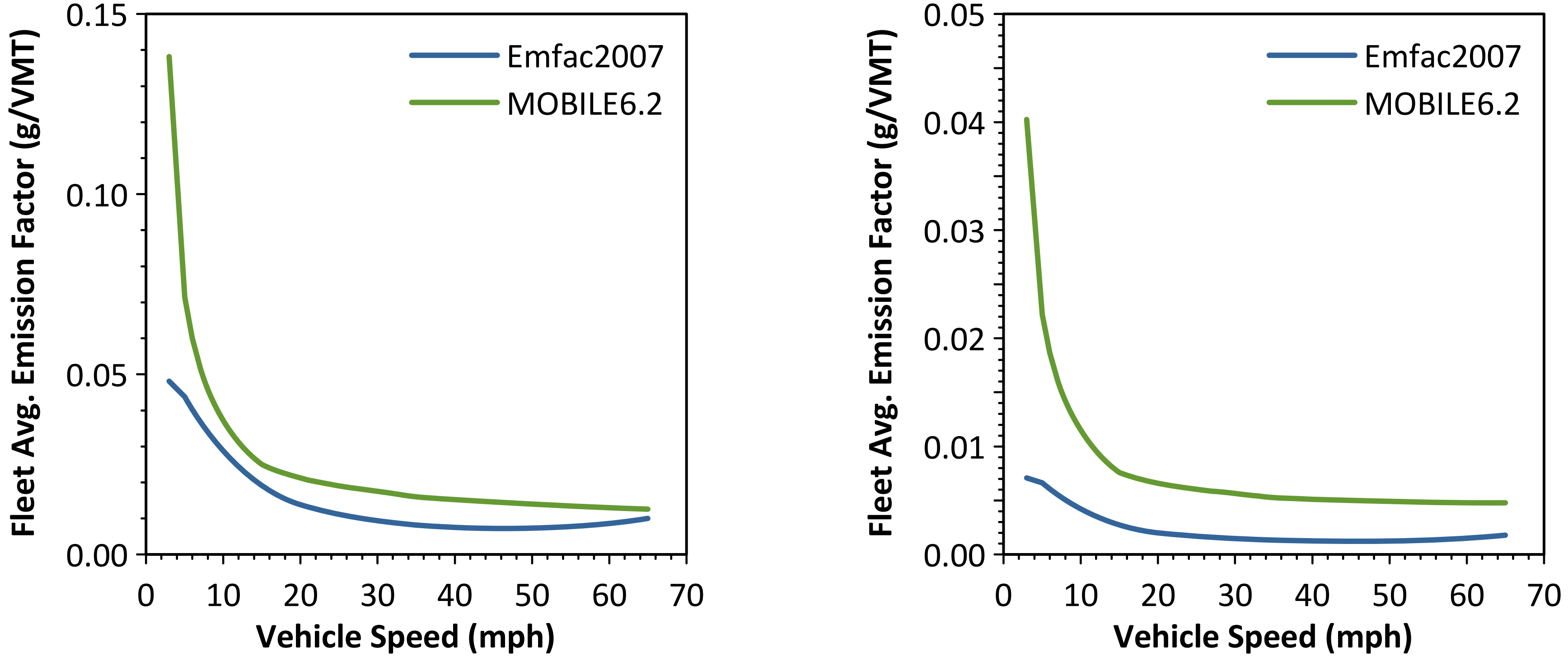

FIGURE 7 Benzene emission factors for calendar years 2005 (left panel) and 2030 (right panel).

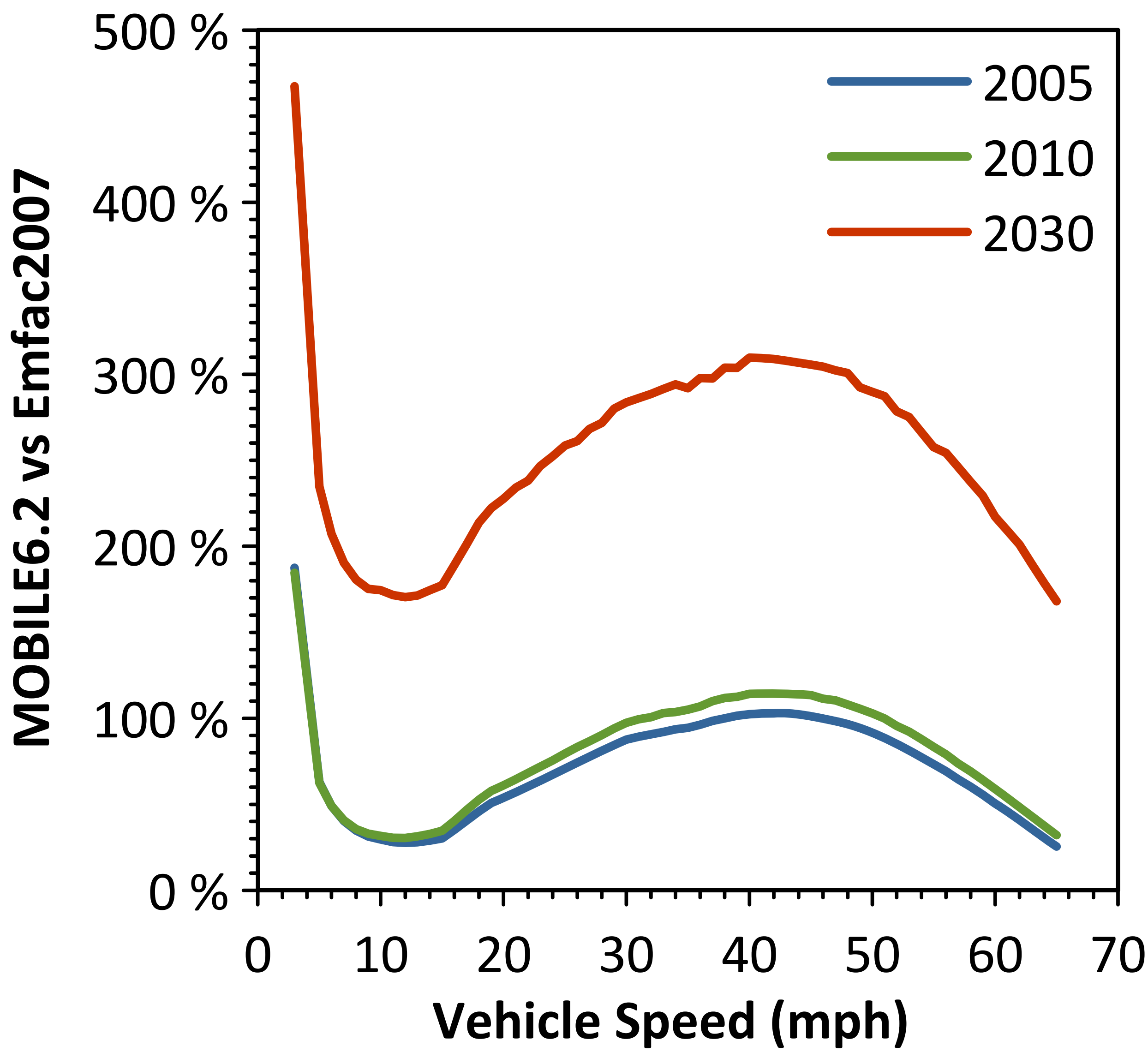

FIGURE 8 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of benzene.

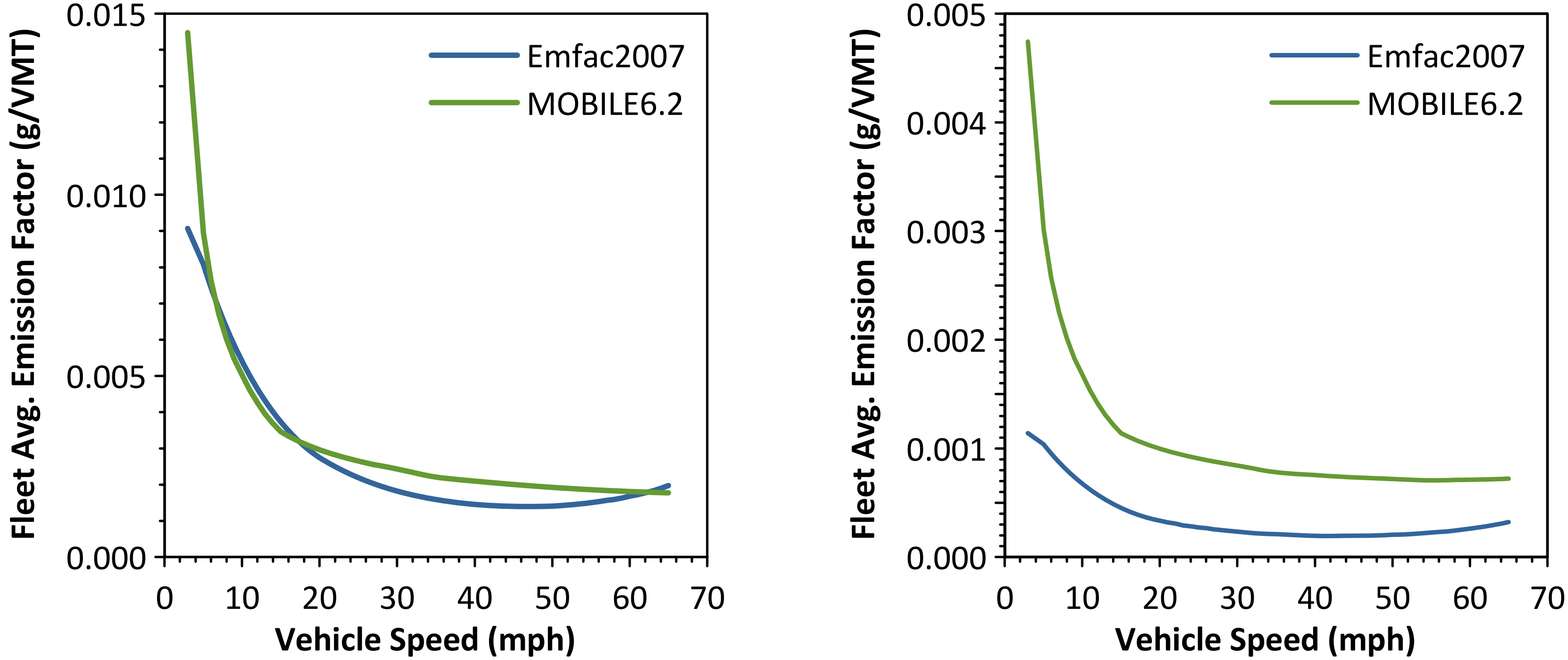

FIGURE 9 1,3 Butadiene emission factors for calendar years 2005 (left panel) and 2030 (right panel).

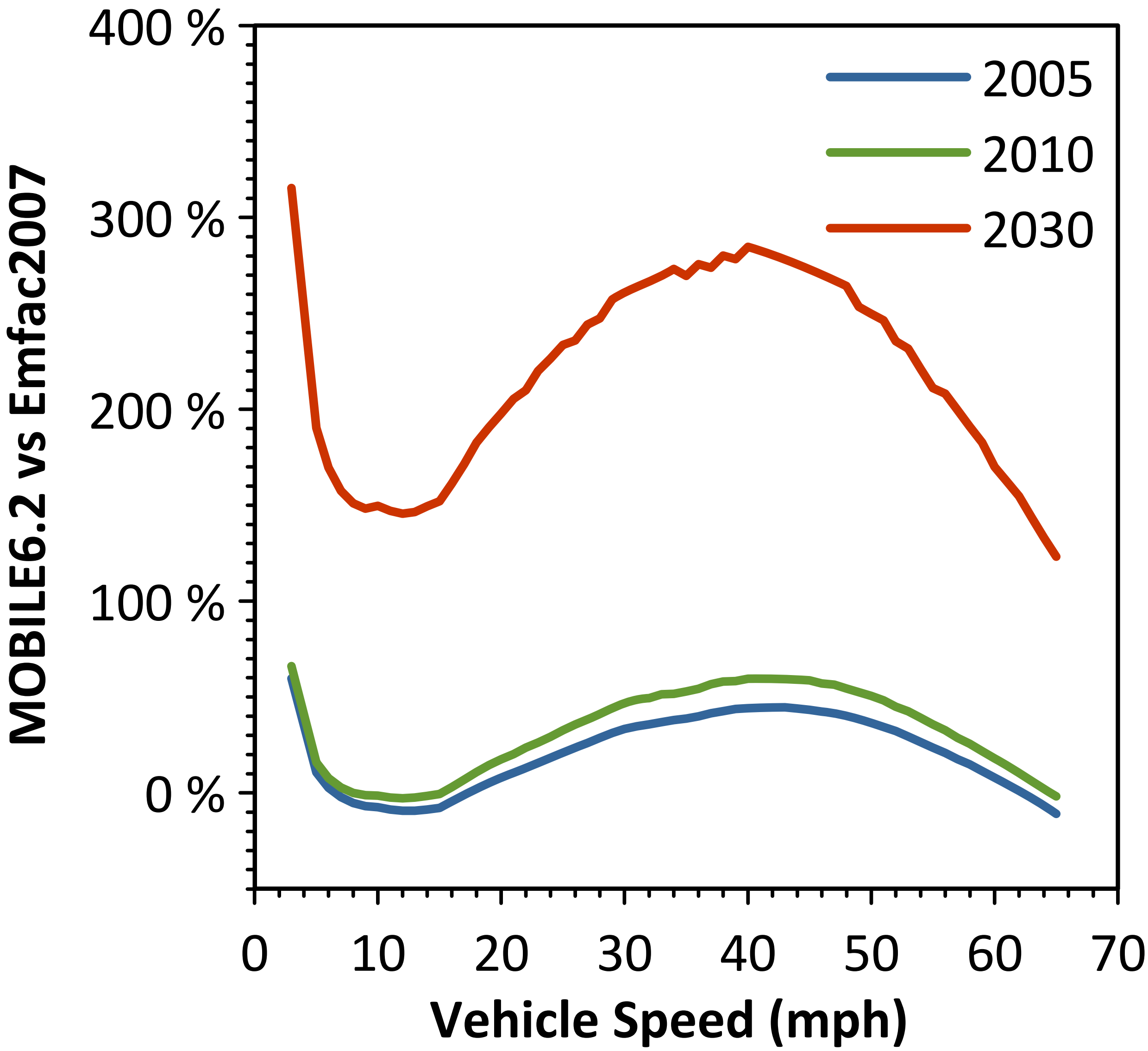

FIGURE 10 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of 1,3 butadiene.

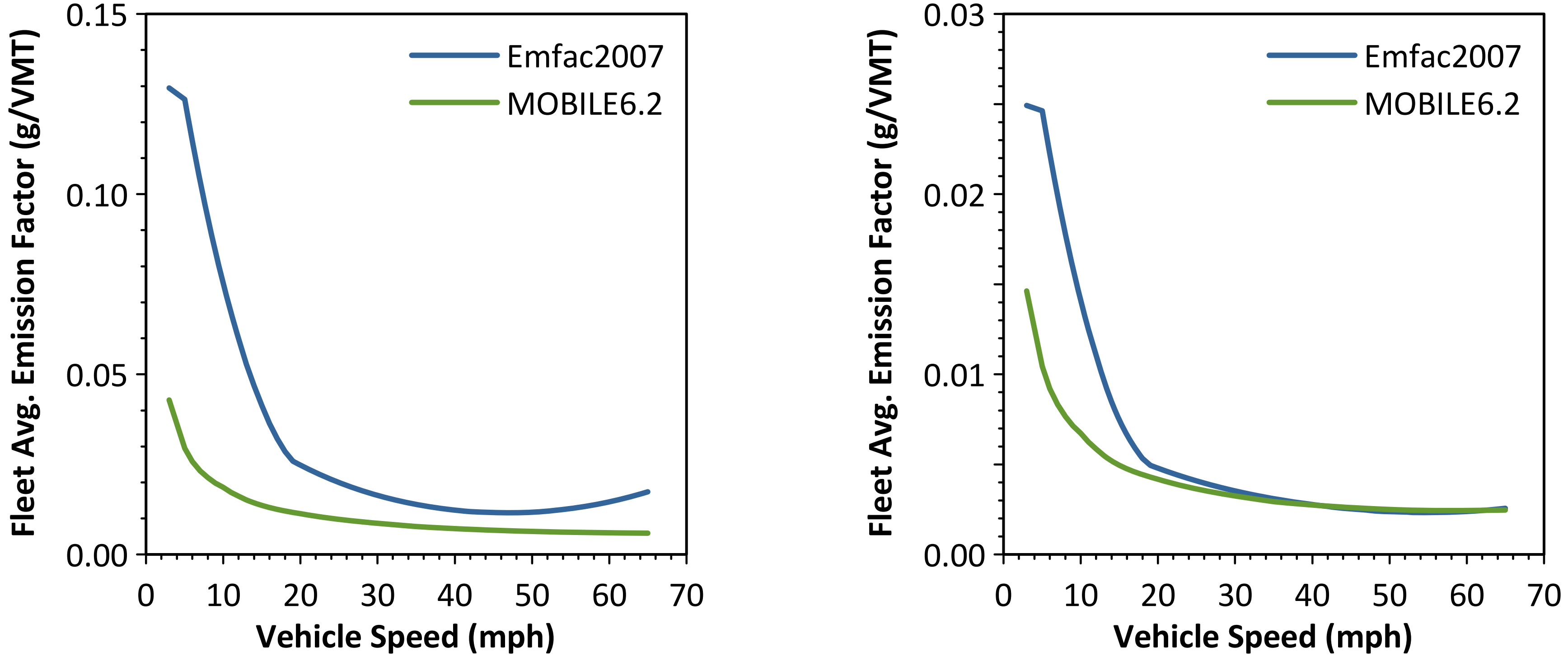

FIGURE 11 Formaldehyde emission factors for calendar years 2005 (left panel) and 2030 (right panel).

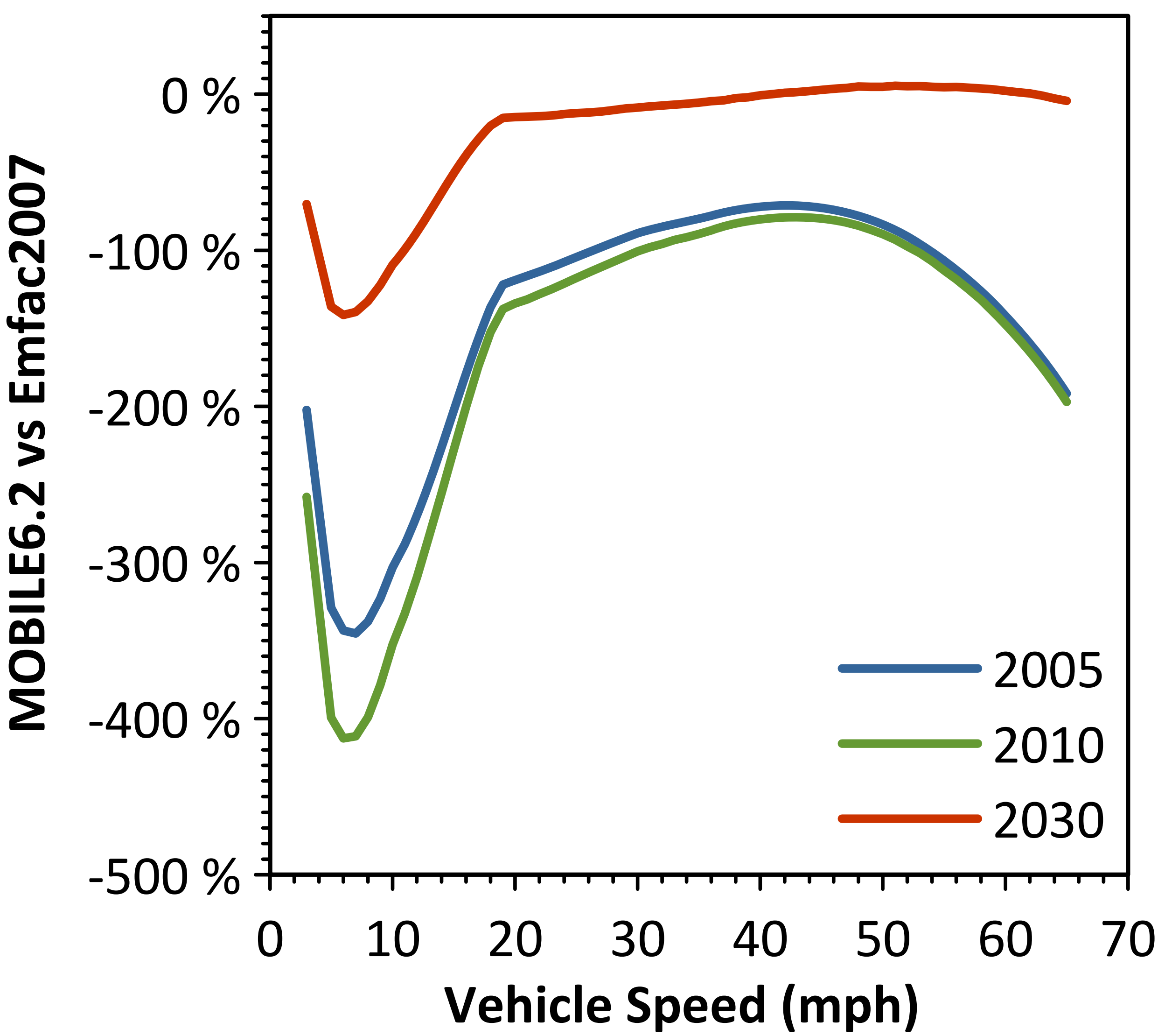

FIGURE 12 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of formaldehyde.

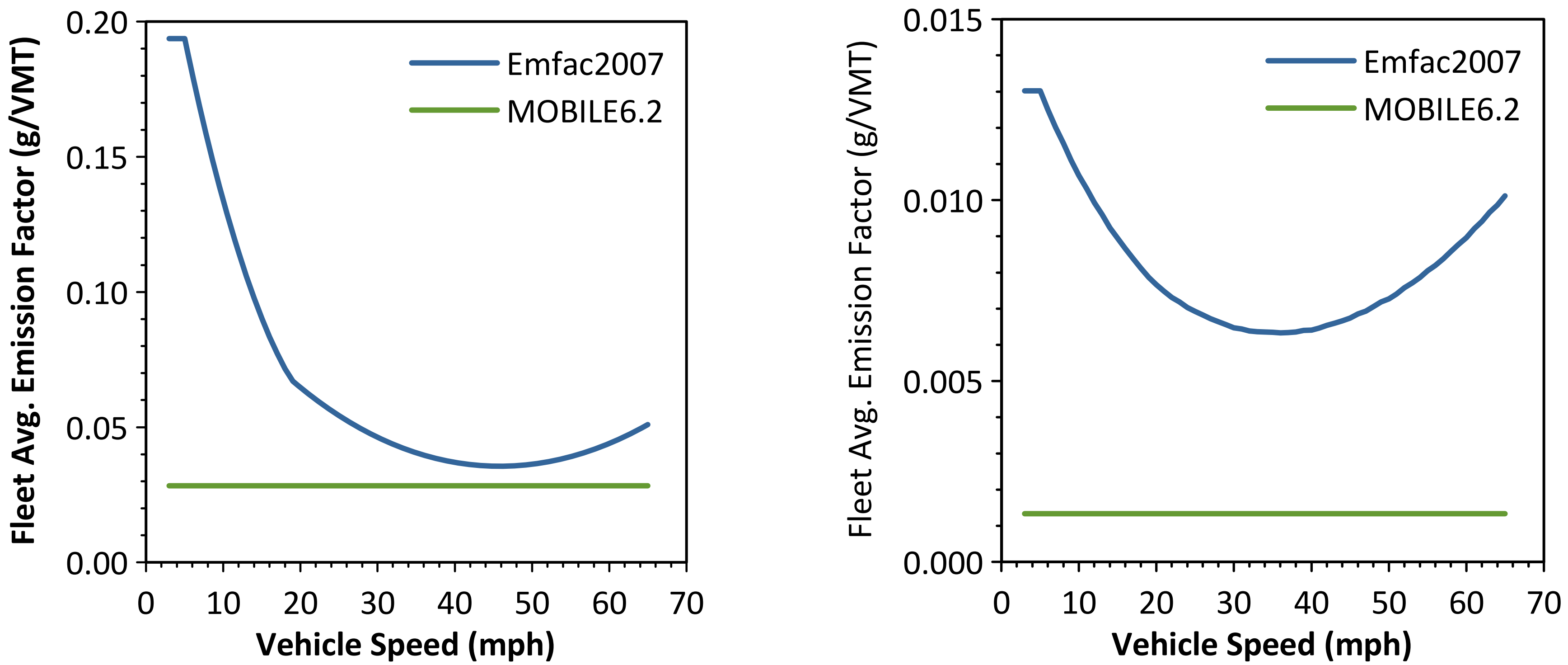

FIGURE 13 Diesel PM emission factors for calendar years 2005 (left panel) and 2030 (right panel).

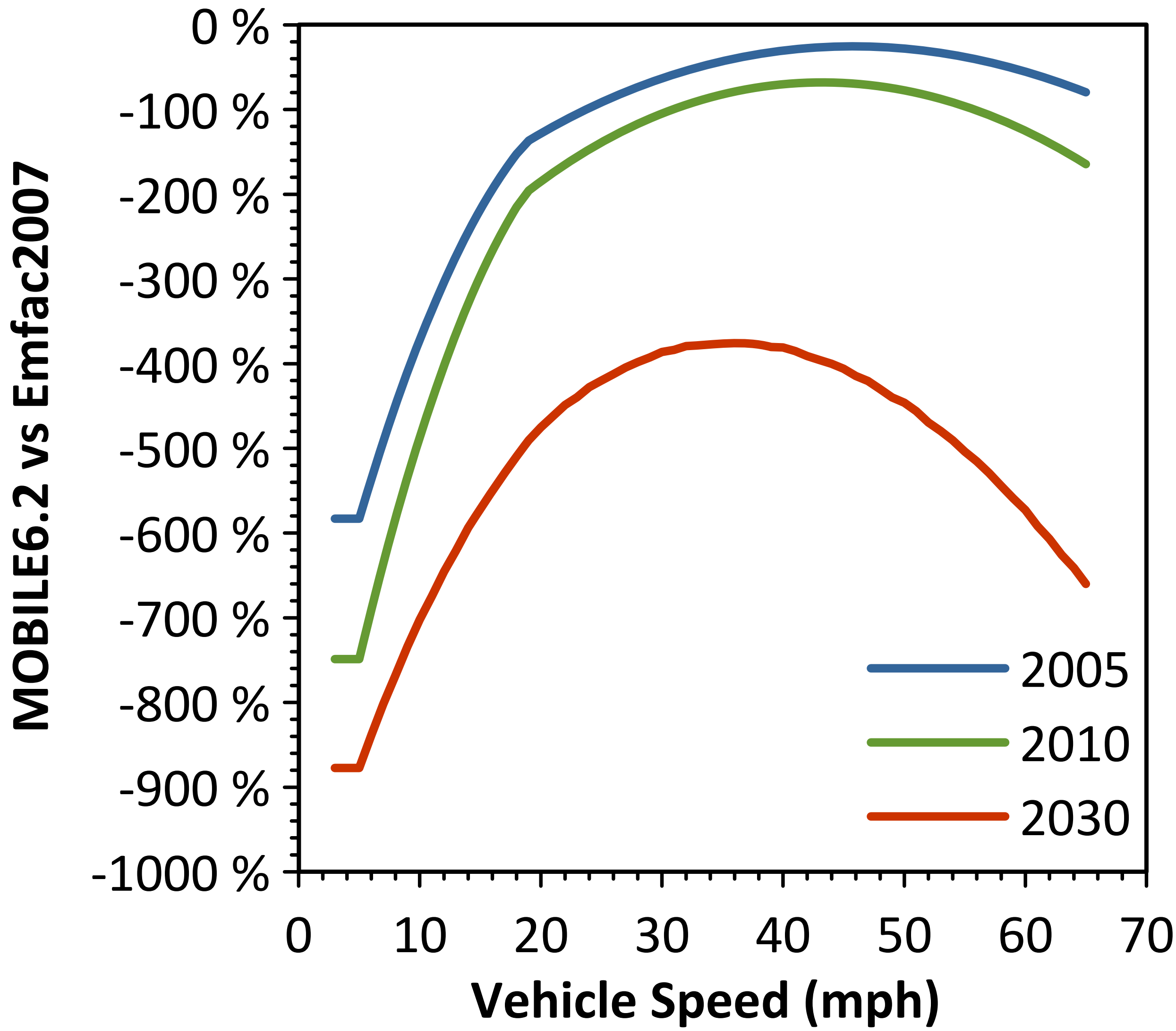

FIGURE 14 Percent differences in MOBILE6.2 versus Emfac2007 emission factors of diesel PM.

acetaldehyde, formaldehyde, and diesel PM compared to MOBILE6.2. Diesel PM emission factors from Emfac2007 vary with vehicle speed; in MOBILE6.2 they do not. There are significant differences in the MSAT speciation factors (TOG weight fractions) used in MOBILE6.2 versus Emfac2007, which accounts for most of the discrepancy in the emission factor results observed. The MSAT speciation ratios developed by the UC Davis-Caltrans Air Quality Project are a generally conservative interpretation of the information published by CARB. UC Davis is currently developing more sophisticated ratios that more comprehensively utilize CARB's speciation information.

Comparing the results obtained from the MOBILE6.2 and Emfac2007 models does not and cannot answer if one model is inherently better or more accurate than the other, but it does provide a realistic measure of model uncertainty, especially with respect to the future outlook for motor vehicle emissions

Admittedly, more research is needed to determine how much of the variability in results obtained with the MOBILE6.2 and Emfac2007 models are a function of differences in the data, assumptions, and methodologies employed. A head-to-head comparison of the two models employing a sensitivity analysis type of approach could be used to quantify some of the observed variability.

DISCLAIMER

The content of this paper solely represents the work of the authors and does not reflect the policy, guidance, or procedures adopted or recommended by the U.S. Department of Transportation and the Federal Highway Administration. This document is disseminated in the interest of information exchange and the U.S. Government assumes no liability for use of the information. This paper does not constitute a standard specification or regulation.

REFERENCES

1. U.S. Environmental Protection Agency (EPA). *User's Guide to MOBILE6.1 and MOBILE6.2, Mobile Source Emission Factor Model*. Publication EPA420-R-03-010. Office of Transportation and Air Quality, 2003.

2. California Air Resources Board (CARB). EMFAC2007 version 2.30, Calculating Emission Inventories for Vehicles in California, User's Guide. 2006.

3. Claggett, M. and J. Houk. An Emission Inventory Tool for Transportation Conformity Applications in Rural and Small Urban Areas. *Proceedings of the 2006 TRB 85th Annual Meeting*. CD-ROM. Transportation Research Board, National Research Council, Washington, DC, 2006.

4. U.S. Environmental Protection Agency (EPA). *Technical Guidance on the Use of MOBILE6.2 for Emission Inventory Preparation*. Publication EPA420-R-04-013. Office of Transportation and Air Quality, 2004.

5. U.S. Environmental Protection Agency (EPA). *Technical Description of the Toxics Module for MOBILE6.2 and Guidance on Its Use for Emission Inventory Preparation*. Publication EPA420-R-02-029. Office of Transportation and Air Quality, 2002.

6. U.S. Environmental Protection Agency (EPA). Control of Hazardous Air Pollutants from Mobile Sources. *Federal Register: February 26, 2007*, Vol. 72, No. 37, Washington, DC, 2007, pp 8427 – 8476.

7. Bia, S., D. Eisinger, and D. Niemeier. *Estimating Mobile Source Air Toxics Emissions: A Step-by-Step Project Analysis Methodology*. University of California, Davis, CA, 2006.

8. U.S. Environmental Protection Agency (EPA). *Facility-Specific Speed Correction Factors, Draft*. Report Number M6.SPD.002. Publication EPA420-P-99-002. Office of Mobile Sources, 1999.

9. California Air Resources Board (CARB). On-Road emission Model Methodology Documentation. Section 6.2, "Speed Correction Factors", 2000. www.arb.ca.gov/msei/onroad/downloads/tsd/Speed_Correction_Factors.doc. Accessed November 15, 2007.